

- 1 -

## DESCRIPTION

## RESONATOR, FILTER, AND COMMUNICATION APPARATUS

## 5 Technical Field

The present invention relates to a resonator, a filter, and a communication apparatus which are used, for example, for wireless communication in microwaves or millimeter waves or for sending and receiving electromagnetic waves.

10

## Background Art

Hitherto, to reduce the size of a resonator using a slot line, a design approach to form the slot line into a stepped impedance structure is known (for example, see

15 "ANALYSIS, DESIGN AND APPLICATIONS OF FIN LINES", Bharathi Bhat, Shibani K. Koul, PP. 316-317 published by ARTECH HOUSE, INC, U.S.A. 1987, and "MAIKUROHA KAIRO NO KISO TO OHYO (BASICS AND APPLICATIONS OF MICROWAVE CIRCUITS), Yoshihiro KONISHI, Sougou Denshi Shuppansha, p. 169 issued in 1990

20 (first edition). In this approach, by forming the widths of both ends of the slot line to be larger and by forming the width of the central portion to be narrower, the impedance of both ends of the slot line becomes inductive and the impedance of the central portion becomes capacitive so that

25 the impedance is changed in a stepwise manner along the

length of the slot line. With this arrangement, the length of the slot line required for obtaining the same resonant frequency can be reduced.

A typical example of the above-described stepped-impedance-structured slot resonator is shown in Fig. 13. In Fig. 13, (B) is a top view illustrating a substrate forming the slot resonator, and (A) is a sectional view taken along line A-A in (B). A conductive film 10 having conductor openings APa, APb, and APc is formed on the top surface of a dielectric substrate 1. The conductor openings APa, APb, and APc form one conductor opening formed, as a whole, in a dumbbell shape. The widths (which can also be referred to as "diameters" since the openings APa and APb in this example are circular) of the conductor openings APa and APb at both ends are formed relatively large and the width of the central conductor opening APc is relatively small. Accordingly, both ends of the slot are inductive, while the central portion of the slot is capacitive.

The broken lines in (A) in Fig. 13 schematically indicate magnetic lines of force of this slot resonator. The magnetic distribution of this resonator is represented by the magnetic lines of force. In the stepped-impedance-structured slot resonator, magnetic field vectors are directed upward in one inductive area at one end, while magnetic field vectors are directed downward in the other

inductive area at the other end, and the overall slot resonator serves as a magnetic dipole. Magnetic field energy produced by the resonance operation mostly concentrates in the inductive areas formed by the conductor openings APa and APb, while electric field energy is mostly distributed in the capacitive area formed by the conductor opening APc. In this manner, by separating the storage area of the magnetic field energy from the storage area of the electric field energy, the slot resonator serves as a lumped-constant circuit, thereby achieving the miniaturization of the slot resonator.

The size of the slot resonator is inversely proportional to the resonant frequency. Accordingly, forming a slot resonator into a stepped-impedance structure as described above is effective in reducing the size of the resonator when the resonant frequency is relatively low. Additionally, a larger impedance step ratio of the capacitive area to the inductive areas is more effective in reducing the size of the resonator.

In the example shown in Fig. 13, therefore, it is effective if the line width of the conductor opening APc is formed to be narrow and if the line length is reduced. However, because of a restriction on the pattern forming precision of the conductive film, the line width cannot be formed to be extremely narrow. Additionally, a change in

the capacitance of the capacitive area caused by dimensional variations in the line width becomes noticeable as the line width becomes narrower. Thus, it is more difficult to obtain a predetermined resonant frequency with high precision as the line width of the conductor opening APc in the capacitive area becomes narrower.

To solve the above-described problems, it is an object of the present invention to provide a resonator, a filter, and a communication apparatus that can be easily miniaturized even if the resonant frequency is relatively low.

#### Disclosure of Invention

According to this invention, a resonator including a dielectric layer and conductor layers is provided. A plurality of conductor layers partially insulated from each other by the dielectric layer are disposed, and at least two conductor openings free from any of the conductor layers in a laminate direction in which the dielectric layer and the conductor layers are laminated are formed as inductive areas, and a portion where the conductor layers oppose each other with the dielectric layer therebetween in the laminate direction, the portion being interposed between the inductive areas, is formed as a capacitive area.

With this configuration, a plurality of conductor

layers are laminated with the dielectric layer therebetween,  
and conductor openings are formed by the conductor layers,  
and a capacitive area is formed in a portion where the  
conductor layers oppose each other in the laminate direction  
5 with the dielectric layer therebetween. Accordingly, a  
predetermined capacitance is generated in a limited area,  
and a small resonator exhibiting a highly precise resonant  
frequency can be obtained.

In this invention, a plurality of the inductive areas  
10 and a plurality of the capacitive areas may be disposed in a  
laminated body including the dielectric layer and the  
conductor layers, and a plurality of sets, each set  
including the inductive areas and the capacitive area  
interposed between the inductive areas, may be disposed.  
15 According to this structure, a plurality of resonators can  
be formed on a single substrate, which serves as the  
laminated body, and also, by coupling those resonators, a  
resonator device including a plurality of stages of  
resonators can be formed.

20 According to this invention, a filter including the  
above-described resonator and signal input/output means  
coupled to the resonator is also provided. According to  
this structure, a small filter can be obtained.

According to this invention, a communication apparatus  
25 including the above-described resonator or filter is

provided. By the provision of this filter, the size of a high-frequency circuit portion including the above-described resonator or filter can be reduced, thereby obtaining a small communication apparatus.

5

#### Brief Description of the Drawings

Fig. 1 illustrates the configuration of a resonator according to a first embodiment. Fig. 2 illustrates the configuration of a resonator according to a second  
10 embodiment. Fig. 3 illustrates the configuration of a resonator according to a third embodiment. Fig. 4 illustrates the configuration of a resonator according to a fourth embodiment. Fig. 5 illustrates simulation results of a change in the resonant frequency and a change in the  
15 conductor Q by using the dimensions of the elements of the resonator shown in Fig. 4 as parameters. Fig. 6 illustrates simulation results of a change in the resonant frequency and a change in the conductor Q by using the dimensions of the elements of the resonator shown in Fig. 4 as parameters.  
20 Fig. 7 illustrates the configuration of a filter according to a fifth embodiment. Fig. 8 illustrates the configuration of essential portions of a resonator according to a sixth embodiment. Fig. 9 is a sectional view illustrating examples of magnetic field distributions in the laminated  
25 portions of a plurality of conductor lines. Fig. 10

illustrates the relationship between the conductor Q and the ratio of the capacitance of the capacitive areas disposed at the outer sides in the direction in which a plurality of capacitive areas are laminated to the capacitance of the capacitive areas disposed at the inner sides. Fig. 11 is a sectional view illustrating examples of other configurations of the capacitive areas. Fig. 12 is a block diagram illustrating the configuration of a duplexer and the configuration of a communication apparatus according to a seventh embodiment. Fig. 13 illustrates the configuration of a known resonator.

#### Best Mode for Carrying Out the Invention

Examples of resonators, filters, duplexers, and communication apparatuses according to the present invention are described below with reference to the accompanying drawings.

A resonator according to a first embodiment is discussed below with reference to Fig. 1.

In Fig. 1, (B) is a top view illustrating the resonator, (A) is a sectional view taken along line A-A in (B), (C) illustrates the pattern of a conductor layer disposed on the top surface, and (D) illustrates the pattern of a conductor layer pattern disposed as the bottom layer.

On the top surface of a rectangular dielectric

substrate 1, a conductor layer 4 having the pattern shown in (D) is formed. A dielectric layer 3 is disposed on the entire top surface of the dielectric substrate 1 on which the conductor layer 4 is formed, and a conductor layer 5 having the pattern shown in (C) is formed on the surface of the dielectric layer 3. With this configuration, a structure in which the conductor layers 4 and 5 are laminated in the thickness direction with the dielectric layer 3 therebetween is formed. In the state in which the conductor layers 4 and 5 are laminated with the dielectric layer 3 therebetween, conductor openings free from any conductor layer are formed, as shown in (B), in the direction in which the conductor layers 4 and 5 and the dielectric layer 3 are laminated.

In this example, by combining semicircular portions SC of a conductor opening APd formed by the pattern of the conductor layer 4 and semicircular portions SC of a conductor opening APu formed by the pattern of the conductor layer 5, circular conductor openings free from any conductor layer in the laminate direction are formed. Those circular conductor openings form inductive areas IAa and IAb.

By the lamination of the conductor layers 4 and 5, a rectangular capacitive area CA is formed in a portion where the inductive areas IAa and IAb face each other with the dielectric layer 3 therebetween. The thickness (gap) of the



dielectric layer 3 is set to be  $1/10$  of the diameter of the circular conductor openings or smaller.

According to this structure, the two inductive areas IAa and IAb and the capacitive area CA interposed between the inductive areas IAa and IAb serve as a stepped-  
5 impedance-structured slot resonator. In this example, since the ratio of the gap of the capacitive area CA to the diameter of the conductor openings is  $1:10$  or greater, about 90% or higher of magnetic field energy produced by the  
10 resonance operation is distributed in the inductive areas IAa and IAb and about 90% or higher of electric field energy is distributed in the capacitive area CA.

The broken lines in (A) schematically represent magnetic lines of force, the shape of which indicate the  
15 magnetic field distribution. Magnetic field vectors are directed upward in one inductive area at one end, while magnetic field vectors are directed downward in the other inductive area at the other end so that the magnetic fields are symmetrically distributed with respect to a point  
20 substantially at  $180^\circ$ . The electric field vectors are distributed while being aligned in the dielectric layer sandwiched between the conductor layers in the capacitive area CA.

If a high capacitance, such as a lumped constant, is  
25 obtained in the capacitive area CA, a current having a small

amplitude change is distributed around the inductive areas IAa and IAb so that the edge effect in the capacitive area can be alleviated. More specifically, magnetic field vectors are distributed around the capacitive area CA, as indicated in (A). However, a current without nodes or loops flows at the edges of the conductor openings forming the inductive areas IAa and IAb, and by the influence of this current, the magnetic fields surrounding the capacitive area CA are expanded so that the curvature becomes gentler, thereby alleviating the edge effect (edge effect is generated by the sharp curvature of magnetic fields). Accordingly, the conductor loss is suppressed, and as a result, a resonator having high  $Q_0$  can be obtained.

Unlike the known dumbbell-shaped slot resonator shown in Fig. 13, since the capacitive area CA is formed in a portion where the two conductor layers 4 and 5 oppose each other with the dielectric layer 3 therebetween in the thickness direction, a predetermined capacitor can be formed in a limited area. As a result, the overall resonator can be miniaturized. Additionally, the capacitive area CA is not opened when viewed in the laminate direction, and instead, the predetermined portions of the conductor layers 4 and 5 oppose each other in the thickness direction with the dielectric layer 3 therebetween. Accordingly, the volume ratio of the capacitive area CA to the entire

resonance space can be decreased, thereby reducing the occurrences of intrusion of the magnetic field energy. That is, the relationship, i.e., the magnetic field energy = volume  $\times$  magnetic field energy density, holds true, and thus, 5 the amount of magnetic field energy becomes smaller as the volume of the capacitive area is smaller. The presence of the magnetic field energy in the capacitive area causes an actual current to flow to maintain such energy, thereby incurring the conductor loss. Accordingly, the conductor 10 loss can be reduced as the magnetic field energy in the capacitive area is smaller. It is thus possible to obtain a small resonator having high unloaded  $Q$  ( $Q_0$ ).

In the example shown in Fig. 1, a shielding electrode 7 is disposed on the four side surfaces and bottom surface of 15 the dielectric substrate 1, and the peripheral portions of the conductor layers 4 and 5 are electrically connected to the shielding electrode 7. Accordingly, the lower half of the above-described resonance space is shielded by the shielding electrode 7. The upper half of the resonance 20 space may also be shielded by covering the top portion of the resonator in the state shown in (A) of Fig. 1 with a conductive cap. As a result, the entire resonance space can be shielded by the conductive cap and the shielding electrode 7.

25 The shielding electrode 7 is not essential since it

does not directly influence the resonance operation. If necessary, a structure in which the shielding electrode 7 is not disposed on the dielectric substrate 1 may be formed.

Fig. 2 illustrates the configuration of a resonator according to a second embodiment. In Fig. 2, (C) is a top view illustrating the resonator, (A) is a sectional view taken along line A-A in (C), and (B) is a sectional view taken along line B-B in (C). In Fig. 2, (D) illustrates the pattern of a conductor layer 5 as the upper layer, and (E) illustrates the pattern of a conductor layer 4 as the lower layer. Unlike the resonator shown in Fig. 1, in this resonator shown in Fig. 2, the conductor layers 4 and 5 are partially electrically connected to each other by interlayer short-circuit portions S on the top surface of the dielectric substrate 1. The dielectric layer 3 is not present in the interlayer short-circuit portions S. According to this structure, the conductor layers 4 and 5 are short-circuited more reliably in the vicinities of the conductor openings by the interlayer short-circuit portions S compared to the structure in which the conductor layers 4 and 5 are short-circuited only by the shielding electrode 7.

Fig. 3 illustrates the configuration of a resonator according to a third embodiment. In Fig. 3, (C) is a top view illustrating the resonator, (A) is a sectional view taken along line A-A in (C), and (B) is a sectional view

taken along line B-B in (C). In Fig. 3, (D) illustrates the pattern of a conductive layer 5 as the upper layer, and (E) illustrates the pattern of a conductor layer 6 as the lower layer.

5        The conductor layer 6 is formed in a predetermined portion on the top surface of the dielectric substrate 1. The conductor layer 5 having the pattern shown in (D) is formed on the top surface of the conductor layer 6 with the dielectric layer 3 therebetween. The conductor opening of  
10   the conductor layer 5 is formed in a dumbbell shape in which generally circular conductor openings APa and APb are formed at both ends and a slot conductor opening APc having a predetermined width is interposed between the conductor openings APa and APb. The conductor layer 6 is formed in a  
15   position near the slot conductor opening APc where the conductor layer 6 does not face the conductor openings APa and APb, which serve as inductive areas, formed at both ends. The conductor layers 5 and 6 oppose each other with the dielectric layer 3 therebetween, and capacitances are  
20   generated between the conductor layers 5 and 6, as shown in (B). This corresponds to an equivalent circuit in which two capacitors are connected in series with each other. Accordingly, a required capacitance can be ensured without the need to form the gap of the slot opening APc to be  
25   extremely small. As a result, as in the first and second

embodiments, a small resonator having high  $Q_0$  can be obtained. By laminating a plurality of conductor layers 5 and 6 alternately, larger capacitances can be obtained.

A fourth embodiment is described below with reference  
5 to Figs. 4 through 6.

In Fig. 4, (B) is a top view illustrating the resonator from which a shielding cap 14 at the top portion is removed, and (A) is a sectional view taken along line A-A in (B). In Fig. 4, (C) and (D) illustrate the patterns of conductor  
10 layers formed as the corresponding layers.

As shown in (A), a laminated portion 45 in which a plurality of conductor layers and corresponding dielectric layers are alternately laminated is disposed in a multilayered substrate 12. As shown in (C) and (D), the  
15 conductor layers 4 and 5 having the two different patterns are laminated with a dielectric layer therebetween. That is, this structure corresponds to a structure formed by laminating the laminate structure consisting of the conductor layers 4 and 5 and the dielectric layer 3 shown in  
20 Fig. 1 in a multilayered form. The conductor layers 4 and 5 are electrically connected to the shielding electrode 7 formed on the four side surfaces and the bottom surface of the multilayered substrate 12. Accordingly, areas free from any conductor layer in the direction in which the dielectric  
25 layer and the conductor layers are laminated serve as the

inductive areas IAa and IAb. An area where the conductor layers face each other with the dielectric layer therebetween serves as the capacitive area CA. In this manner, by forming the capacitive area CA by laminating a plurality of conductor layers and corresponding dielectric layers, the size of the capacitive area can be reduced, and a smaller resonator can be obtained.

By covering the top portion of the multilayered substrate 12 with the conductive shielding cap 14, a shielded resonator having the top space S can be formed.

The multilayered substrate 12 can be manufactured by a manufacturing method for a laminate multilayered substrate including processes of pattern formation by printing a conductive paste on a dielectric ceramic green sheet, and laminating, pressing, and firing of the sheet. Alternatively, a method for sequentially printing dielectric layers and conductor layers on a substrate and then firing the substrate may be employed.

Figs. 5 and 6 illustrate simulation results of the resonant frequency and the conductor Q when the dimension parameters of the corresponding elements of the resonator shown in Fig. 4 are changed. In Figs. 5 and 6, the width of the capacitive area CA is indicated by W, the depth of the overlapping portion of the conductor layers is represented by G, and the diameter (opening diameter) of the conductor

openings, which serve as inductive areas IAa and IAb, is designated by D. The horizontal length and the vertical width of the multilayered substrate 12 are indicated by L and M, respectively. It is now assumed that L is 2.4 mm and M is 1.2 mm, and that the thickness of the multilayered substrate 12 is 0.5 mm and the thickness of the top space S formed by the shielding cap 14 is 0.5 mm.

Fig. 5 illustrates simulation results when G is changed under the three conditions that D = 0.3 mm, 0.4 mm, and 0.6 mm by fixing the width W of the capacitive area CA to be 0.4 mm. In (A), the horizontal axis represents G, and the vertical axis indicates the resonant frequency. In (B), the horizontal axis represents the resonator frequency, and the vertical axis indicates the conductor Q. The conductor Q represents the magnitude of the conductor loss.

Since the capacitance is increased in accordance with an increase in the depth G, the resonant frequency is reduced, as shown in (A) in Fig. 5, in inverse proportion to the capacitance. As the opening diameter D becomes larger, the resonant frequency becomes lower. This is because, as the opening diameter D becomes larger, magnetic fluxes passing through the conductor opening are increased, thereby increasing the induction quantity.

As shown in (B), as the opening diameter D becomes larger, the conductor Q at the same frequency becomes higher.



Fig. 6 illustrates simulation results when the depth  $G$  of the capacitive area is changed under the conditions that the width  $W$  of the capacitive area is 0.4 mm, 0.5 mm, and 0.6 mm by fixing the diameter  $D$  of the conductor opening to be 0.6 mm. As in Fig. 5, in (A), the horizontal axis represents  $G$ , and the vertical axis indicates the resonant frequency. In (B), the horizontal axis represents the resonator frequency, and the vertical axis indicates the conductor  $Q$ .

Since the capacitance is increased as the depth  $G$  of the capacitive area becomes increased, as shown in (A) in Fig. 6, the resonant frequency is reduced in inverse proportion to the capacitance. The dependency of the resonant frequency on the width  $W$  of the capacitive area seems to be small. This is probably because the reduced capacitance due to a decrease in the width  $W$  of the capacitive area and the increased induction quantity are well balanced.

As shown in (B) in Fig. 6, the dependency of the conductor  $Q$  on the width  $W$  of the capacitive area is not noticeable. This result shows that the conductor loss is not increased even if the width  $W$  of the capacitive area is decreased. Thus, the resonator can be miniaturized.

An example of the configuration of a filter according to a fifth embodiment is discussed below with reference to

Fig. 7.

In Fig. 7, (D) is a top view of the filter, and (A) is a sectional view taken along line A-A in (D). In Fig. 7, (E) is a front view of the filter, (B) is a sectional view taken along line B-B in (E), and (C) is a top view (plan view taken along line C-C in (E)) of the filter from which the shielding cap 14 is removed. In the multilayered substrate 12, a plurality of conductor layers having two different patterns are alternately laminated with a dielectric layer therebetween, as in the structure of the multilayered substrate 12 shown in Fig. 4. With this arrangement, three inductive areas IAa, IAb, and IAc and two capacitive areas CAa and CAB interposed between the inductive areas IAa and IAb and between the inductive areas IAb and IAc, respectively, are disposed.

As shown in (A) and (B), input/output coupling electrodes 8a and 8b are formed at positions away from the laminated portion of the two conductor layer patterns of the multilayered substrate 12. One end of each of the input/output coupling electrodes 8a and 8b is electrically connected to the shielding electrode 7 formed at the side surfaces of the multilayered substrate 12, and the other ends of the input/output coupling electrodes 8a and 8b are electrically connected to input/output terminals 9a and 9b, respectively. According to this structure, the input/output

coupling electrodes 8a and 8b and the shielding electrode 7 form a coupling loop.

A set of the two inductive areas IAa and IAb and the capacitive area CAa serves as a single (first stage) resonator, and a set of the two inductive areas IAb and IAc and the capacitive area CAb serves as a single (second stage) resonator. The magnetic field distributions of the two resonators are indicated by the broken lines in (A), and the input/output coupling electrodes 8a and 8b are magnetically coupled with the corresponding resonators. Thus, this filter serves as a filter exhibiting bandpass characteristics obtained by two stages of resonators.

Although in the example shown in Fig. 7 two stages of resonators are formed, three or more stages of resonators may be similarly formed on a single substrate. In this case, since two inductive areas and a capacitive area interposed between the inductive areas serve as a single resonator, one of the two inductive areas of one resonator is used as one of the two inductive areas of the adjacent resonator. Accordingly, a structure in which the resonators are sequentially coupled with each other can be formed.

A resonator according to a sixth embodiment is described below with reference to Figs. 8 through 11.

In the first through fifth embodiments, the capacitances of the capacitive areas in the individual

layers of the resonators are not specifically indicated. In the sixth embodiment, the capacitances of the capacitive areas in the individual layers are differentiated in the thickness direction.

5       The configuration of the overall resonator according to the sixth embodiment is similar to that shown in Fig. 7. The patterns of the conductor layers formed for the corresponding dielectric layers of the multilayered substrate are different from those shown in Fig. 7.

10       Fig. 8 illustrates the patterns of the conductor layers formed for the corresponding dielectric layers of the multilayered substrate. In Fig. 8, (A) illustrates the pattern of a conductor layer as a first layer (topmost layer), (B) illustrates the pattern of a conductor layer as  
15 a second layer, (C) illustrates the pattern of a conductor layer as a third layer, (D) illustrates the pattern of a conductor layer as a fourth layer, and (E) illustrates the pattern of a conductor layer as a fifth layer (bottommost layer). Reference numerals 41, 51, 42, 52, and 43 indicate  
20 conductor layers.

In Fig. 9, (A) is a sectional view taken along line A-A in (A) in Fig. 8. Similarly, in Fig. 9, (B) is a sectional view taken along line B-B in (B) in Fig. 8. In Fig. 9, (C) and (D) illustrate comparative examples in relation to (A) and (B), respectively, which are discussed below.  
25

In Fig. 9, the broken lines H indicate the distribution of magnetic fields surrounding the capacitive area CAa.

As shown in (B) in Fig. 9, the area of the overlapping portion of the conductor layer 41 as the first layer

5 (topmost layer) and the conductor layer 51 as the second layer is indicated by  $S_o$ , the area of the overlapping portion of the conductor layer 51 as the second layer and the conductor layer 42 of the third layer is represented by  $S_i$ , the area of the overlapping portion of the conductor  
10 layer 42 as the third layer and the conductor layer 52 as the fourth layer is represented by  $S_i$ , and the area of the overlapping portion of the conductor layer 52 as the fourth layer and the conductor layer 43 as the fifth layer is indicated by  $S_o$ .

15 In the example in (B), the relationship  $S_o > S_i$  holds true. That is, the capacitance  $CA_o$  of the capacitive areas disposed at the outer sides in the laminate direction is set to be greater than the capacitance  $CA_i$  of the capacitive areas disposed at the inner sides in the laminate direction.

20 In the example in (D), the relationship  $S_o = S_i$  holds true. That is, the capacitances  $CA_o$  and  $CA_i$  of the corresponding layers of the capacitive areas are set to be equal to each other.

Fig. 10 is a diagram illustrating the relationship  
25 between the conductor Q and the ratio of the capacitance  $CA_o$

of the capacitive areas disposed at the outer sides in the direction in which a plurality of capacitive areas are laminated to the capacitance  $CA_i$  of the capacitive areas disposed at the inner sides in the laminate direction. When  
5  $CA_o/CA_i = 1$ , i.e.,  $CA_o = CA_i$ , the conductor  $Q$  is about 290. When  $CA_o/CA_i = 4$ , the conductor  $Q$  is improved to about 330. Accordingly, as  $CA_o/CA_i$  becomes greater, the conductor  $Q$  ( $Q_c$ ) is improved.

The operational advantages by the improved  $Q_c$  are  
10 discussed below with reference to Fig. 9.

As discussed in the individual embodiments, conductor openings free from any conductor layer in the direction in which dielectric layers are laminated serve as inductive areas, while the portion interposed between the inductive  
15 areas where the conductor layers are laminated with the corresponding dielectric layer therebetween serves as a capacitive area. In the resonator formed by the inductive areas and the capacitive area, the intensity of magnetic fields generated in the inductive areas becomes greater as  
20 the capacitance of the capacitive area is larger.

When the capacitance of the capacitive areas at the outer sides (outer layers) in the thickness direction is greater than that of the capacitive areas at the inner sides (inner layers) in the thickness direction, as shown in (A)  
25 and (B) in Fig. 9, among the five conductor layers 41, 51,

42, 52, and 43, the current flowing in the outer layers becomes greater than that flowing in the inner layers so that the magnetic fluxes generated by the current flowing in the outer layers becomes greater than those generated by the current flowing in the inner layers. On the other hand, when the capacitances of the capacitive areas of the individual layers are equal to each other, as shown in (C) and (D) in Fig. 9, substantially the same magnitude of current flows in the five conductor layers 41, 51, 42, 52, and 43, and thus, the magnetic fluxes generated by the current flowing in the inner layers and those generated by the current flowing in the outer layers become substantially equal to each other. Accordingly, the distribution of the magnetic fields surrounding the capacitive area CAa shown in (A) is expanded farther in the thickness direction compared to the magnetic field distribution shown in (C). In the case of (C), the locally circulating magnetic fields intrude into the capacitive areas of the inner layers where the conductor loss is generated.

The relationship among the unloaded  $Q$  ( $Q_0$ ), the conductor  $Q$  ( $Q_c$ ), and the dielectric  $Q$  ( $Q_d$ ) of the resonator is expressed by the following equation (1).

$$\frac{1}{Q_0} = \frac{1}{Q_c} + \frac{1}{Q_d} \quad \dots(1)$$

In equation (1),  $Q_c$  can be expressed by the following

equation (2).

$$\frac{1}{Q_c} = \frac{W_{m1}}{W_{m1} + W_{m2}} \cdot \frac{1}{Q_{c1}} + \frac{W_{m2}}{W_{m1} + W_{m2}} \cdot \frac{1}{Q_{c2}} \quad \dots(2)$$

In equation (2),  $Q_{c1}$  is the conductor  $Q$  of the conductor lines of the outermost layers (topmost layer and bottommost layer) of the laminated conductor lines, and  $Q_{c2}$  is the conductor  $Q$  of the inner layers other than the outermost layers.  $W_{m1}$  is the magnetic field energy stored in the outermost layers, and  $W_{m2}$  is the magnetic field energy stored in the inner layers. Since  $Q_{c2}$  is smaller than  $Q_{c1}$  by about two orders of magnitude,  $Q_c$  can be enhanced by reducing the influence of  $Q_{c2}$  to be smaller than that of  $Q_{c1}$ . This can be implemented by decreasing  $W_{m2}$ . To decrease the magnetic field energy  $W_{m2}$  stored in the inner layers, the current flowing in the conductor lines 21 and 25 of the outermost layers is set to be relatively large in relation to the current flowing in the conductor lines of the inner layers. In order to implement this, the capacitance of the capacitive areas of the outermost layers is set to be relatively large in relation to that of the inner layers.

Fig. 11 illustrates two examples of the configuration of a resonator in which the capacitance of the outermost layers is greater than that of the inner layers. In (B) in Fig. 9, the distribution of the capacitances in the



thickness direction is determined by varying the areas of the opposing portions of the conductor layers. In the example in (A) in Fig. 11, however, the dielectric constant of the dielectric layer sandwiched between the first  
5 conductor layer 41 and the second conductor layer 51 is set to be greater than that sandwiched between the third conductor layer 42 and the fourth conductor layer 52. Similarly, the dielectric constant of the dielectric layer sandwiched between the fifth conductor layer 43 and the  
10 fourth conductor layer 52 is set to be greater than that sandwiched between the fourth conductor layer 52 and the third conductor layer 42. With this arrangement, the capacitance of the capacitive areas of the outer layers can be larger than that of the inner layers.

15 In the example in (B) in Fig. 11, the thickness of the dielectric layer sandwiched between the second conductor layer 51 and the third conductor layer 42 is set to be greater than that sandwiched between the first conductor layer 41 and the second conductor layer 51. Similarly, the  
20 thickness of the dielectric layer sandwiched between the third conductor layer 42 and the fourth conductor layer 52 is set to be greater than that sandwiched between the fourth conductor layer 52 and the fifth conductor layer 43. With this arrangement, the capacitance of the capacitive areas of  
25 the outermost layers can be larger than that of the inner

layers.

As described above, by reducing the magnetic field energy intruding into the capacitive areas of the inner layers,  $Q_c$  can be improved.

5        In the above-described examples, to determine the capacitances of the capacitive areas of the layers, the capacitive areas are divided into two groups, i.e., the capacitive areas in the outermost layers and the capacitive areas in the other layers. Alternatively, the thickness or  
10      the dielectric constant of each dielectric layer or the area of the opposing portions of the conductor layers may be determined so that the capacitance is progressively increased as the capacitive area goes from the central portion toward the outer layers.

15        The configurations of a duplexer and a communication apparatus according to a seventh embodiment are shown.

      In Fig. 12, (A) is a block diagram illustrating a duplexer. A transmission filter and a reception filter are each formed of the filter having the configuration shown in  
20      Fig. 7. The pass bands of the transmission filter TxFIL and the reception filter RxFIL are designed in accordance with the corresponding bands. The transmission filter TxFIL allows signal components of the transmission frequency band of a signal input from a transmission-signal input terminal  
25      TxT to pass through the transmission filter TxFIL to an

antenna terminal AntT. The reception filter RxFIL allows signal components of the reception frequency band of a signal input from the antenna terminal AntT to pass through the reception filter RxFIL to a reception-signal output terminal RxT.

In connecting the transmission filter TxFIL and the reception filter RxFIL to the antenna terminal AntT, which serves as a duplexer terminal, phase adjustment is made so that a leakage of a transmission signal to the reception filter RxFIL and a leakage of a reception signal to the transmission filter TxFIL can be prevented.

In Fig. 12, (B) is a block diagram illustrating the configuration of a communication apparatus. As the duplexer DUP, the duplexer having the configuration shown in (A) is used. A transmission circuit Tx-CIR and a reception circuit Rx-CIR are mounted on a circuit board. The duplexer DUP is mounted on the circuit board so that the transmission circuit Tx-CIR is connected to the transmission-signal input terminal of the duplexer DUP and the reception circuit Rx-CIR is connected to the reception-signal output terminal of the duplexer DUP and so that the antenna ANT is connected to the antenna terminal.